

Pioneer 11 Saturn Encounter Mission Support

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TDA Mission Support

Pioneer 11 spacecraft flew by the planet Saturn in August and September 1979. The DSN performance during the support of the first Saturn encounter is described.

I. Introduction

The Pioneer 11 spacecraft was launched on 6 April 1973, and flew by the planet Jupiter with the closest approach on 3 December 1974. After nearly six and one-half years of flight, the Pioneer 11 spacecraft flew within 1.33 Saturn radii of the planet Saturn on 1 September 1979. The trajectory, major mission events, and mission objectives were described in Ref. 1. The overall Deep Space Network (DSN) support plans were also described in Ref. 1 with a more detailed description of operational plans and specific configurations for support of the encounter in Ref. 2.

Although the references should be consulted for more details, the key DSN efforts in support of the Pioneer 11 Saturn encounter are summarized below. The efforts fell in four major areas.

The first major area of DSN support was trying to obtain satisfactory data return at Saturn with a spacecraft designed for a Jovian distance. The activities included the installation of lower noise S-band ruby masers at the overseas stations, and the use of the listen-only mode at the 64-meter diameter antennas while simultaneously transmitting for command purposes from 34-meter diameter stations. At Goldstone an experimental real-time combiner was used to array the large and small antennas. In addition, all telemetry reception stations put in an extensive effort in selecting the "best" of

what would ordinarily be considered "identical" equipment in order to eke out every fraction of a dB of improved performance. Telemetry recovery at each station involves a string of equipment from receiver through subcarrier and bit detection to telemetry processing, and the selection process involves testing redundant equipment to select the best performing combination of equipment at a particular station.

The second major area was concerned with taking extra precaution to avoid losing any data during the critical ring plane crossing and periapsis. Besides special procedures, equipment originally installed for the Pioneer-Venus Multiprobe entry was modified and re-implemented as a means of recovering the telemetry data after the fact, without real-time coherent detection, in the event the data were lost in real time. As it turns out, things seem to have gone well enough in real time that it should not be necessary to process any of these data except for a few minutes at enter occultation.

The third major area was to accommodate the very high doppler rates of up to 70 Hz per second that occurred during closest approach. This was accommodated at the 64-meter stations by using the existing programmable local oscillator (PLO) capability of pre-programming rates into the receivers. PLO-controlled receivers were not available at DSS 12, the 34-meter station at Goldstone, and in order to retain that station's receivers in lock as a part of the arraying, PLO control for the receivers were installed on a temporary basis.

There was late identification of an impact on radio science due to the long round-trip light time where extensive amounts of two-way data would not be available. The losses occur at station handovers and, most important, for the critical day of closest approach because of the high doppler rates and the fact that only the 34-meter stations were two-way, and PLO control for the receivers had not been planned and was not available for the Spanish station, DSS 62. When this problem was identified, the personnel at DSS 62 took it upon themselves to put together a team of receiver operators who manually tuned the receivers for several hours of high-rate doppler, spelling each other in a round-robin fashion to relieve fatigue. By this means, DSS 62 was able to provide good two-way doppler for the majority of the pre-closest approach pass, except for a brief time period where the rates were greater than even the manual tuning could accommodate.

The last major area was the need to provide the Project a means of safing the spacecraft and continuing major sequences in the event of the loss of ground communications or the computers at the control center at the Ames Research Center. This involved a potential use of manual real-time commanding well beyond that which the system was originally designed to accommodate. This effort involved special procedures and an extensive amount of testing and training for all station crews to support this contingency commanding activity. In the actual mission, it never became necessary to call on this capability.

II. DSN Performance During Week Leading to Closest Approach

All of the efforts in trying to improve telecommunications performance were aimed at the objective of trying to achieve a 1024-bps data rate for the Saturn encounter. The principal driver for this data rate was the imaging photopolarimeter. This instrument constructs images by a spin-scan method, where for each rotation of the spacecraft the equivalent of one line of the image is taken over a portion of the spin and that line must be read out over the remainder of the spin period before the next line of data is taken. The field of view of the instrument is 28 degrees of roll, and it takes a 1024-bit rate in order to read all of the data back before the buffer is overwritten by the next scan line. If it is necessary to lower the data rate to 512 bps, there are two choices in the imaging mode of the instrument. First is to let the next scan line overwrite the buffer before the previous scan line is completely read out, and this means that only one-half of the scan line would be recovered, which, therefore, results in a picture only 14 degrees high instead of 28 degrees high, but with the same resolution. There is a second possible choice, which is to change the instrument to a lower resolution mode that retains

the 28 degrees field of view but with essentially half the resolution. For a more detailed description of this instrument, see Ref. 3.

In the early part of August, based on previous test data and available predictions of the effect the sun would have on the telecommunications link, it was anticipated that 1024 bps would be possible for on the order of three or four hours around zenith in Australia, five or six hours around zenith in Spain. Because of the additional performance added by the arraying, it was anticipated that 1024 bps should be possible for eight hours at Goldstone. In August, early tests of the arraying for the Pioneer case were not successful, and, in fact, over the entire encounter period, a monumental effort was required to get the arraying operating and keep it operating for the encounter. It must be remembered that the real-time combining equipment involved in the arraying is experimental and not operational equipment. Also, the arraying depended heavily on having the proper equipment performance outside of the real-time combiner at both stations. Over the course of the month, the majority of problems found with the arraying were actually outside of the real-time combiner itself. For example, a lot of the early failures at DSS 14 were isolated to poorer performance near threshold of the Block IV Subcarrier Demodulator Assemblies (SDAs) at the specific Pioneer 11 data rate of 1024 bps compared to the Block III SDAs.

The first planned arraying support of the encounter on 25 August, seven days before closest approach, found the arrayed pair of DSSs 12 and 14 performing very well with a gain of 0.4 to 0.5 dB compared to the non-arrayed overseas sites. The listen-only Australian DSS 43 track, which followed on 26 August, had very poor quality data at 1024 bps. The weather was quite bad on this track with occasional heavy rainfall, and the missing performance was attributed to this fact at the time. The Spanish listen-only track went as expected; however, the Goldstone-arrayed track on Sunday, 26 August, showed no apparent gain. The basis for judging the arraying was that one telemetry string would be operated on the output of the real-time combiner at DSS 14, while the redundant telemetry string was operated on the uncombined signal at DSS 14. On this particular day, there was no difference in performance observed between these two strings. An extensive troubleshooting effort took place at DSSs 12 and 14 between the time of this and the next track with nothing discovered to explain the lack of observed gain. It was felt at the time that the problem may have been in the microwave link between DSSs 12 and 14, but this was never confirmed. For Monday's Australian track, the Project elected to stay at 512 bps because of predicted potential bad weather. The Spanish track continued to have usable 1024 bps, while the following arrayed DSS 12 and 14 track found the arraying to be working perfectly again.

For the next Australian track on 28 August, the Project again elected to stay at 512 bps, and the Spanish track did not attempt any 1024 bps, since the listen-only mode was not used, in order to perform the last precession maneuver until after closest approach. Between tracks Australia was also making special efforts to do testing in order to be assured that they were using the best possible configuration from a performance standpoint. The weather explanation for their poorer performance was not entirely satisfying.

During the arrayed track on 28 August following the precession maneuver, at the scheduled time that the Project had commanded to go to 1024 bps, due to an error the spacecraft stayed in a mode with its feed offset used for consscanning; therefore, the telemetry performance was lower than predicted. This resulted in a round-trip light time of nearly three hours, wherein it was not possible to lock the unarrayed telemetry system at DSS 14 at all. The telemetry data out of the arrayed telemetry string had a very high deletion rate, but was still usable. For this entire time period, it was elected to put both telemetry strings at DSS 14 on the output of the real-time combiner. In other words, if it had not been for the real-time combiner, this three hours of data would have been a total loss. For the following Australian track on 29 August, the Project again elected to remain at 512 bps (Note: times and dates are quoted in GMT, and for the Australian tracks the GMT date is one day later than for PST). The quality of the 1024-bps data at the Spanish station on 29 August was poorer than expected, and the evidence was piling up that something else was going on besides weather problems in Australia. The arrayed 1024-bps data at Goldstone on 29 August was of acceptable quality, although the system noise temperature was registering higher than at previous tracks at DSS 14. On the 30 August Australian track, the Project again elected to stay at 512 bps; however, the signal-to-noise ratio computed by the telemetry system indicated that four hours of 1024 bps would have been possible during that track. During the following Spanish track, the Spaniards reported RFI observed at both the 34-meter and 64-meter stations, but the feeling was developing that what we were really observing was the sun affecting the telecommunications link a full eight days sooner than anticipated and in a more random off-again-on-again fashion in telemetry than in previously observed solar superior conjunctions. Note that on the day of closest approach, the spacecraft was 8 degrees from the sun and closing as observed from the Earth.

The criterion for "good" 1024-bps data was set by the Project as about a 1 percent frame deletion rate. It was discovered in these various bouts of "bad" 1024-bps data from Spain and earlier from Australia that, when the deletion rate got up in the region of 7 percent, the Ames Research Center computer system would go off-line, and no 1024-bps data

could be observed at all by Ames in real time. This compounded the problems of trying to assess the telecommunications performance because the key criterion for valid 1024-bps data was the frame deletion rate, and the DSN computation of the frame deletion rate was different from the Ames computation and was not reliable for looking at real-time changes in performance. There were two reasons for the off-lining of the computers at Ames: the additional computer time used in printing alarms when the deletion rate climbed, and the fact that Ames was observing the incoming data as being bursty in time. That is, the data did not flow at a steady rate into the computers, but, rather, there would be a pause and then several frames hit the computer at one time. At first it was thought that this was caused by error correction-detection not being turned off or some other problem in the communications computer at the tracking station, but it turned out to be a natural characteristic of how the convolutional decoder is implemented at the deep space station. In the DSN implementation, when a frame cannot be successfully decoded, the software will give up to four frame times to decode that frame and then the following three frames will be given only a single frame time, so that frames are not lost. When operating on the ragged edge of threshold (or actually below threshold as we were during this encounter), non-regular spacing of the data flow would result. Note that when this problem occurred the data were only lost to Ames in real time and could be played back from the tracking station after the fact.

The fields and particles experimenters at Ames were very concerned about the amount of data that was not seen in real time and the general corruption of their data in trying to achieve high enough data rate to maximize the imaging return. This meant that there was pressure to reduce the "experimentation" with trying to maintain the 1024 bps and to take a more conservative approach.

However, on the next Australian track, based on the measured performance on the previous Australian track and the preceding arrayed track at Goldstone, the Project elected to try for 1024 bps during the time period when the last full planet view was possible before the planet would exceed the field of view of the imaging photopolarimeter. The first 1024-bps data for the Australian track looked very good; however, it was characteristic of the stochastic nature of the effect the sun was having that, by the time of the arrival on the ground of that last full planet picture, the system noise temperature at DSS 43 had climbed several degrees and the deletion rate had grown to well over 10 percent. It was then decided that, for the remainder of the encounter, the overseas sites would remain at 512 bps and that 1024 bps would be used at Goldstone for zenith $\pm 2\frac{1}{2}$ hours. The coup de grace to the 1024 bps at the overseas sites was a brief period of 1024 bps

on 31 August at Spain, which had a frame deletion rate of approximately 8 percent. On the day of closest approach, the 512 bps data were of very good quality, but the computed signal-to-noise ratio indicated that the margin was insufficient for 1024 bps and that the decision to remain at 512 bps had been wise. The 1024 bps at Goldstone with the arraying after closest approach was of good quality and again for the Titan picture on the day after closest approach. The total uncertainties in the look direction to Titan (the combination of trajectory uncertainty and the IPP pointing uncertainty) were sufficiently great that, if the Project had been forced to use 512 bps for the Titan picture, they would probably have elected to have gone to the lower resolution mode of the instrument. This was another time when the arraying really paid off for the mission.

The need to reduce the data rate to 512 bps at the overseas stations was a bit of a disappointment because of the tremendous manpower that was consumed at the overseas sites in trying to maximize their performance. However, if that effort had not been extended, it is quite likely that even the 512 bps would not have been achieved, and, in fact, the Project may have had to have gone to as low a data rate as 128 bps. The net result was a return of something on the order of twenty pictures better than Earth-based resolution instead of the anticipated forty pictures if 1024 bps had been achievable at all stations. However, even with the need to reduce the data rate due to solar noise, the science return was still extensive and more than anyone had anticipated before the encounter. In fact, the Pioneer Saturn Imaging Team stated that they had greater scientific return from the Pioneer 11 Saturn encounter than they had from both the Pioneer 10 and 11 Jupiter encounters. It should be noted that some of the most highly published pictures from the encounter were images received at 512 bps (full resolution, half height) at overseas stations.

One other incident of note during the encounter was degradation of the infrared image of Titan due to interference from a Soviet satellite. There had been previous communications enlisting cooperation from the Soviets with regard to two satellites which were potential interference threats, and a third satellite in this family was launched the Wednesday before closest approach. Russian cooperation was enlisted for the day of closest approach and the day after closest approach during the Titan visual imaging; however, for a variety of reasons Russian cooperation was not specifically requested for the time period of receipt of the infrared image of Titan, which occurred two days after closest approach. The Spanish station experienced interference of varying degrees of severity for several hours two days after closest approach. For an approximately 40-minute time period, no telemetry data could be recovered at all, and this encompassed the original estimate of when the Titan picture would be received on the ground. Subsequent analysis revealed that the Titan image was really 20 minutes later than first expected; however, the unintentional interference from the Soviet satellite resulted in a loss of on the order of 14 percent of the raw telemetry data which, according to the experimenter, resulted in only about 50 percent of the infrared data being usable because of the way in which the infrared data are commutated in the spacecraft telemetry.

III. Summary

Despite the sun's degradation of the telecommunications link performance, the efforts of the Deep Space Network resulted in a greater data return than thought possible just one year before encounter. Many new discoveries were made, and the science return was greater than anyone could have hoped, especially when it is remembered that an encounter of Saturn was not in the original design or definition of the Pioneer 10 and 11 missions.

References

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3. Miller, R. B., "Pioneer 10 and 11 Mission Support," *Deep Space Network Progress Report*, Technical Report 32-1526, Volume 16, pp. 15-21, Jet Propulsion Laboratory, Pasadena, Calif., Aug., 15, 1973.